BOREHOLE RADAR SURVEYS IN THE BORTH ROCK SALT MINE (FRG)

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INTRODUCTION

The Borth salt deposit (FRG) lies in the Zechstein basin, which covers a large part of Central Europe. The mine is located north-east of Duisburg. Although the deposit is over 150 metres thick, only the lower part is mined here. Mining activity (approx. 800 metres below surface) is restricted to a 20 m thick layer of extremely pure white salt.

The general structure of the deposit is simple, with nearly horizontal layers. However, several faults cross the area, resulting in a locally complex geometry: anhydrite uplifts and folds.

The salt excavation in the Borth mine takes place in a room and pillar system. Between the main roadways rooms of about 600 metres length, 20 metres width and 20 height are excavated. The mining method of the rooms is an underhand stoping technique. A drift is advanced with a TBM or heading by drilling and blasting during a first phase. This drift lies in the top of a 20 m thick layer in about 6 m distance from a hanging clay layer. The whole salt layer is excavated by underhand work in a second phase.

RADAR INVESTIGATION HISTORY

The Borth rock salt mine has a long tradition and history in radar investigations. First experimental radar surveys were carried out in the 1980s by German and American scientists. The good penetration and low attenuation of the radar waves were a main supposition for a systematic radar exploration from drifts with reliable commercial ground penetration radar (GPR) systems since 1988 especially by the university of Liege - Belgium ([1]). First radar measurements were started out of existing drifts. The disadvantage of conventional subsurface radar measurements is that they can only give an additional structural information from already excavated drifts. A minimization of mining losses needs an optimal planning of salt mining. Therefore knowledge about the bedding of the clay layers in the hanging wall and the anhydrite in the lying wall in front of the face have a very high priority for effective mining. The development of the Swedish borehole radar system RAMAC within the international Stripsa Project on underground nuclear repositories and commercial availability allowed realization of geological exploration from horizontal boreholes. It is carried out in the Borth mine systematically since 1990 by the company EBRA-TEC, a joint venture between K-UTEC (Germany) and G-TEC (Belgium).
BOREHOLE RADAR METHODOLOGY

Borehole radar is a geophysical technique using electromagnetic impulses in a frequency range between 20 MHz and 60 MHz. The techniques may be used in two different modes (Fig. 1):
- reflection mode (transmitter and receiver antennas in the same borehole), giving a detailed structural image of the rockmass surrounding the borehole;
- transmission or tomographic mode (transmitter and receiver antennas in two separate boreholes), giving an image of the rockmass between the boreholes.

![Borehole Radar Section](image)

**REFLECTION MODE**

Fig. 1: Principles of borehole radar reflection and tomographic measurements

Dipole or omnidirectional and directional receiver antennas exist for investigations in the reflection mode. The use of directional receiver antenna is the only available geophysical technique giving a 3D image of the rockmass surrounding a borehole.

**GEOPHYSICAL EXPLORATION OF UNWORKED AREA**

Since 1990 borehole radar investigations were carried out before drifts are excavated. In the first years only main roadways and some rooms in difficult geological areas with anhydrite uplifts and folds were investigated. Since 1994 all drifts and further rooms of the mine are drilled in advance with horizontal boreholes and measured with the borehole radar reflection technique. The horizontal boreholes are normally 400 to 600 metres long. With a special anchor technique, developed by the Borth mine for measurements in brine filled boreholes, the radar probe configuration is moved to the end of the horizontal borehole. After that, the radar measurement takes place from the end of the hole step by step every 1 metre by using an automatic winch with a special optical borehole cable. Measuring boreholes with lengths up to 2000 m metres are possible.

The knowledge of the exact bedding of the hanging clay layer, a very thin clay layer of only several millimetres thickness, is necessary for layout of new excavations. In order to control roof stability for later excavation of drifts and rooms, the roof of the drift has to have a minimum distance to the clay layer of about 6 metres. The vertical position of the TBM or drilling...
and blasting drift is determined to secure this minimum distance to the main clay layer with the borehole radar results of measurement along the borehole axis of the future room. The knowledge of the structural conditions of the lying anhydrite is decisive for the planning of the maximum possible excavation height of the room during the second mining phase. Customers need salt of a very high purity and this requires an excavation of salt without any anhydrite components. Abrupt uplifts of the lying anhydrite layer from one to several metres are typical for the Borth salt deposit. Only with borehole radar results along the future room it is possible to localize these uplifts and to determine their dimensions before the excavation of the rooms can be started. This knowledge allows planning of the position and maximum height of the room to reduce mining losses and to guarantee high salt quality as needed.

EXAMPLE - CASE HISTORY

Since 1990 more than 50 boreholes were measured with the described borehole radar technique. The following representative example in figure 2 shows the efficiency of the method for geological exploration of salt deposits from measurements in a 400 metres long horizontal borehole. Several major reflectors are clearly identified:

- The reflectors A and B correspond to thin clay layers located above the borehole axis. The reflection B comes from the main clay layer (very important for planning of the drift).
- Reflector C correlates with the contact between salt and the massive anhydrite in the lying wall. This contact is uneven with local uplifts.
- The reflector E correspond to two previous boreholes. One of them exposes the lying anhydrite.

The first 90 m the borehole was free of brine. The other part of the hole was filled with brine resulting from the drilling process. Normally borehole radar measurements are impossible in a high conductive borehole fluid medium. The example shows that measurements under special conditions (small borehole diameter in comparision with the probe diameter, surrounding rocks with very high resistivities) are possible in brine filled boreholes. The differences in the amplitudes between the measurement in brine and in air show the high attenuation of the primary electromagnetic energy by the brine. But the main reflectors are important for the geological interpretation and reliable to determine.

All borehole radar investigations in the Borth mine were carried out with a 60 MHz-dipole antenna. Geological correlation of the reflections from the hanging and lying wall are possible and well defined. A few additional surveys with the directional antenna confirmed this statement.

CONCLUSIONS

Borehole radar technique from horizontal boreholes approximately 400 to 500 metres long was successful integrated into geological exploration of the solid rock salt in front of the face. Commercial GPR systems are used after several years of experimental testing. Measurements are now performed on a routine schedule. Today the borehole radar technique out of advancing galleries is an important tool for geological and structural exploration work at Borth salt mine. Very exact determination of the distances to the hanging main clay layer and the lying anhydrite is needed for an effective planning of the mining of very pure salt. Beside the borehole radar reflection technique, the following other radar techniques are commercial used in salt mines:

- Additional subsurface radar measurements from drifts for a detail structural exploration especially of the 20 metres thick usable rock salt layer to the lower lying anhydrite.
• Roof radar measurements for localization of dangerous scalings of the roof; these measurements are an important supposition for the security of personnel and mining equipment.
• Crosshole or tomographic measurements between boreholes for characterization of anhydrite impurities in the rock salt for quality control.

Fig. 2: Radar section and geological interpretation of a borehole radar reflection measurement

REFERENCES